Virginia Whole Farm Planning:

An Educational Program for Farm Startup and Development

VIRGINIA Beginning Farmer & Rancher COALITION PROGRAM

Sustainable Farming Practices: Soil Management

The purpose of the *Sustainable Farming Practices: Soil Management* module is to help beginning farmers and ranchers in Virginia learn the basic fundamental production practices and concepts necessary to make informed decisions for whole farm planning.

This is one of five modules designed to guide you in developing the whole farm plan by focusing on the following areas:

- Introduction to Whole Farm Planning
- Marketing
- Whole Farm Business Management and Planning
- Land Acquisition and Tenure
- Sustainable Farming Practices

Each module is organized at the introductory to intermediate stage of farming knowledge and experience. At the end of each module, additional resources and Virginia service provider contact information are available to help continue the farm planning process.

Virginia Cooperative Extension

Virginia Tech • Virginia State University

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Preface

Welcome to the Virginia Beginning Farmer and Rancher Coalition Project's Whole Farm Planning Curriculum!

How to use this Workbook. This material is organized into five modules that may be used as stand-alone resources to address specific areas of whole farm planning. However, we suggest that the modules may be most beneficial to beginning farmers and ranchers if they are used as a series of educational sessions designed to encourage reflection, goal setting, and steps to organize a new farming enterprise.

Advice for Beginning Farmers. We encourage you to begin by exploring the Introduction to Whole Farm Planning module. This resource will offer you the opportunity to examine your personal and business goals and priorities. Once you have completed this introduction module, you are welcome to explore the other resources in a sequence that best addresses your questions and ideas for your farming enterprise.

Advice for Service Providers. Thank you for choosing to use our curriculum in your whole farm planning educational program. As an experienced education service provider, we encourage you to adapt these resources to best serve the needs of people you work with. The materials are intended to be used as stand-alone pieces or in various combinations of instructional formats, as needed by your program participants.

Modules. Each module is organized at the introductory to intermediate stage of farming knowledge and experience. At the end of each module, additional resources and Virginia service provider contact information are available to help continue the farm planning process.

Module I. Introduction to Whole Farm Planning – The purpose of the first module is to help beginning farmers and ranchers in Virginia make informed farm planning decisions by introducing them to the whole farm planning process.

Module II. Marketing – The marketing module is designed to help beginning farmers and ranchers develop and implement their goals for market analysis, product establishment, and development of viable marketing channels.

Module III. Whole Farm Business Management – In this module, you will develop and implement early financial and resource management goals as part of the whole farm plan.

Module IV. Land Acquisition and Tenure – This module will help beginning farmers and ranchers to develop and implement farm tenure and transfer goals as part of the whole farm plan. Established farmers who are planning for the transfer of their farm may also find this module useful.

Module V. Sustainable Farming Practices – The last module is designed to help beginning farmers and ranchers develop and hone their skills and knowledge in the fundamental production practices associated with establishing and growing a wide range of plants and animals. This module is divided into five sections, each focused on specific aspects of production agriculture: 1. The Place and the Products; 2. Farm Biodiversity; 3. Organisms in the Ecosystem: Beneficials, Pests and Diseases; 4. Soil Management; 5. Animal Husbandry.

Why this Curriculum? The Beginning Farmer Situation

Emerging trends in U.S. agriculture suggest that in order to enhance our agricultural resource base, we need to establish, sustain, and preserve our farms, farmers, and farmland. A growing number of nongovernmental groups, cooperative extension services, and U.S. Department of Agriculture agencies are working to improve the viability of new farms and the economic, social, and environmental fabric in which they are entrenched (Niewolny and Lillard 2010). These initiatives are responding to the overwhelming concern about the steady decline in the number of individuals entering into agriculture, coupled with an increase in the number of exiting farmers and ranchers (Ruhf 2001).

The current population of beginning farmers and ranchers is diverse and varies by location across the nation (Ahearn and Newton 2009). Beginning farmers on average operate smaller farms — in size and gross dollars — compared to established farmers (Ahearn, Yee, and Korb 2005). While beginning farmers tend to be younger than established farmers, about a third of beginning farmers are at least 55 years of age or older (Ahearn and Newton 2009). Beginning farmers, along with limited-resource and socially disadvantaged farmers, make up at least 40 percent of all U.S. farms (Nickerson and Hand 2009).

The Bureau of Labor Statistics (U.S. Department of Labor 2009) recently reported a large job decline for farmers and ranchers and projects an 8 percent decrease in the number of farmers and ranchers between 2008 and 2018. The age distribution of today's farmers and ranchers is also a critical issue. According to the "2007 Census of Agriculture" (USDA-NASS 2009a), the average age of a principal farmer is 57 years old. More than 63 percent of all established farms in 2007 were headed by a principal farmer age 55 or older; only 5 percent of all principal farmers were 35 or younger (Ahearn and Newton 2009). The aging population of U.S. farmers and ranchers is expected to increase by the next census while the number of young farmers is likely to decline.

The 2007 Virginia census also illustrates a significant need to establish and retain beginning farmers and ranchers based on the economic structuring of the industry. Agriculture provides $55 billion in income per year and about 357,000 jobs, making it an important industry for the commonwealth. Of the 47,383 farms in Virginia, 92 percent reported less than $100,000 in sales, while 8 percent of the total farms accounted for 85 percent of total farm sales (USDA-NASS 2009b).

Virginia is also among the most expensive states for farmland, making it difficult for aspiring agriculturists to purchase suitable acreage. The average farm comprises 171 acres, while 77 percent of the total farms in Virginia operate on fewer than 180 acres (USDA-NASS 2009b).

Little is known about the 13,206 principal farmers in Virginia who have been on their current farms or ranches for nine or fewer years. The majority of all farmers in Virginia are white males, though the number of minority farmers such as women and African Americans is on the rise (USDA-NASS 2009b). Production crops and practices differ regionally and culturally, especially between rural and urban centers. Consumer demand for local and regional food, however, is growing at an increasing rate throughout Virginia.

Background on the USDA Beginning Farmer Rancher Development Program (BFRDP)

Beginning farmer education for adult and young audiences in the United States can be generally traced back to the advent of the 1862 and 1890 Morrill Land Grant Acts. But for the first time, the Food, Conservation, and Energy Act of 2008 (the 2008 Farm Bill), appropriated $75 million for fiscal year 2009 to fiscal year 2012 to develop and offer education, training, outreach, and mentoring programs to enhance the sustainability of the next generation of farmers.

The reasons for the renewed interest in beginning farmer and rancher programs are:
• The rising average age of U.S. farmers.
• The 8 percent projected decrease in the number of farmers and ranchers between 2008 and 2018.
• The growing recognition that new programs are needed to address the needs of the next generation of beginning farmers and ranchers.

According to the 2008 Farm Bill, a beginning farm is considered one that is operated by one or more operators who have 10 or fewer years of experience operating a farm or ranch. In 2007, approximately 21 percent of family farms met that definition.

Since its inception, BFRDP has funded many projects to train, educate, and provide outreach and technical assistance to beginning farmers on one or more of the following topics:
• Production and management strategies to enhance land stewardship by beginning farmers and ranchers.
• Business management and decision support strategies that enhance the financial viability of beginning farmers and ranchers.

• Marketing strategies that enhance the competitiveness of beginning farmers and ranchers.
• Legal strategies that assist beginning farmers with farm or land acquisition and transfer.
• Other priority topics to enhance competitiveness and sustainability of beginning farmers and ranchers for the next generation.

Background on the Virginia Beginning Farmer and Rancher Coalition Project

The Virginia Beginning Farmer and Rancher Coalition Program aims to improve opportunities for beginning farmers and ranchers to establish and sustain viable agricultural operations in Virginia through the development and enhancement of whole farm planning programs, online resources, and farmer mentoring networks.

Beginning Farmer Audience

This curriculum is aimed at addressing the needs of the spectrum of beginning farmers and ranchers in Virginia. We recognize a diversity of farming experiences, backgrounds, and aims held by Virginia's beginning farmers and ranchers. Many groups find it useful to look at the stages of commitment, decision-making, and skills that farmers pass through as they begin a career in farming. Drawing on the work of Sheils (2004), the following categories are a helpful guide to understanding this pathway.

Prospective or explorer farmers – Individuals interested in starting a farm or ranch. This includes next-generation farm family members as well as those who do not come from a farming background.

Startup farmers – Individuals who are in the early stages of their agricultural operation, often within the first one to three years of farming or ranching.

Re-strategizing farmers – Farmers who are making changes to their operations after farming for approximately four to seven years. These individuals usually have increased decision-making responsibility and commitment to farming.

Establishing farmers – Farmers who are expanding, diversifying, and stabilizing within years eight to 10 of the beginning farmer period.

Transitioning farmers – Individuals who are family farm members who have decision-making roles on the farm without having primary farm operator status.

These categories of farmers are a modification of those referred to by the New England Small Farm Institute. For the full reference, see "What Does the Term 'Farmer' Mean?"(Sheils 2004).

Preface written by Kim Niewolny and Matt Benson, Department of Agricultural and Extension Education, Virginia Tech.

Acknowledgements

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Organizational Members of the Virginia Beginning Farmer and Rancher Coalition

The Virginia Beginning Farmer and Rancher Coalition comprises innovative farm businesses and organizations from across the Commonwealth. These include:

AgrAbility Virginia
Agricultural Development, Fauquier County
Appalachian Sustainable Development
Attimo Winery
Bracketts Farm
Farm Service Agency, U.S. Department of Agriculture
Fauquier Education Farm
Grayson LandCare
Hethwood Market
Laurel Farm
Local Food Hub
Mountain View Farm and Vineyard
Natural Resource Conservation Service, U.S. Department of Agriculture
Piedmont Environmental Council
Rural Development, U.S. Department of Agriculture
SustainFloyd
Virginia Association for Biological Farming
Virginia Cooperative Extension
Virginia Department of Agriculture and Consumer Services
Virginia Farm Bureau Young Farmers
Virginia Farm Credit
Virginia Forage and Grasslands Council
Virginia State University
Virginia Team Ag Ed
Virginia Tech
VT Earthworks
Young Farmers of Virginia

Steering Committee

The Steering Committee consists of seven committed individuals from the Coalition who represent both farmer and service provider perspectives in Virginia. This elected committee is responsible for guiding project activity to best address the expressed needs of the Coalition.

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The Virginia Beginning Farmer and Rancher Coalition Program is a collaborative effort represented by a range of beginning farmer stakeholders across the Commonwealth of Virginia. It is housed in Virginia Tech's Department of Agricultural and Extension Education. Funding is sponsored by the Beginning Farmer and Rancher Development Program (BFRDP) of the USDA-National Institute of Food and Agriculture (NIFA), Award # 2010-49400. To find more resources and programs for beginning farmers and ranchers please visit www.Start2Farm.gov, a component of the Beginning Farmer and Rancher Development Program. Contact Kim Niewolny, Program Director, at niewolny@vt.edu or 540-231-5784, for more information.

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www.vabeginningfarmer.org

Sustainable Farming Practices: Soil Management

Planning to Teach this Module

Primary resource materials for this module:

Clark, A (ed.). 2007. Managing cover crops for profitability. Sustainable Agriculture Network, Handbook No. 9). 248 pp.

Magdoff & Van Es. 2009. Building Soils for Better Crops, 3rd Edition

Magdoff, F. 2007. Ecological Agriculture: Principles,
practices, and constraints. Renewable Agriculture and Food Systems 22:109-117.

Tugel et al. 2000. Soil Biology Primer. Soil and Water Conservation Society

Virginia Association for Biological Farming information sheets on
soil and cover crops. *www.vabf.org,* click on Library and Resources

In preparation for the planning activities used in this module, we recommend participants…

Contact your Natural Resources Conservation Service (NRCS) district office to find out what soil series (types) are present on your farm, and learn more about your soils at the NRCS web page, Official Soil Series Descriptions, *http://soils.usda.gov/technical/classification/osd/index.html*.

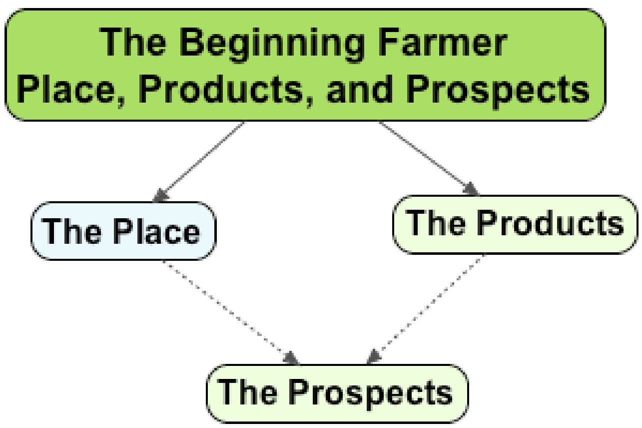
Sustainable Farming Practices Module is divided into five Sections

1. ***The Place and The Products***
2. ***Farm Biodiversity***
3. ***Soil Management***
4. ***Non-Crop Organisms in Agroecosystems***
5. ***Animal Husbandry***

Introduction

Assess where you are

In the Introduction to Whole Farm Planning Module you began a discussion that included your inventory and goals. This module consists of three units that will help you better assess your existing or potential farm situation (Unit 1: The Place), further defining and refining your farm products (Unit 2: The Products), and to assist in selecting appropriate management tools to sustain your farm (Unit 3: The Practices).



Do you know where you want to farm, or already own the land? Your focus moves to assessing that place, deciding which products are suitable, and which will be most effective in helping you achieve your plan.

Do you already know what products you want to raise? Are there other you should consider? Your focus moves to finding a place that provides the biophysical needs for your products, aligns with your cultural expectations, and offers effective economic opportunities.

Perhaps you already know the place and have a good idea which products you would like to raise. Congratulations! But seldom do place and products match perfectly. Your focus will be to gain insight into factors that may affect productivity, marketing, or community interactions. Here is an opportunity to verify the suitability of your earlier decisions, to double check some things you may have overlooked, and perhaps to gain an understanding of the obstacles you will need to overcome to realize your vision of a sustainable farm operation.

Finally, you will need to use sustainable practices to improve, maintain, and protect your products and the farm resources needed to produce them. How will you deal with pests and avoid diseases? How will you ensure soil fertility and productivity? What will you do when the rains do not come? How will you manage the land that is not used for raising products? How will you protect herd or flock health, and deal with questions of animal housing?

Reflecting on your responses, does your previous discussion of the sustainable farming practices of your plan still accurately represent your whole farming plan?

Assess where you want to be.

What are your particular questions regarding your planning for your sustainable farming practices?

What do you need to get there?

Individuals who complete this module

The *Sustainable Farming Practices* module is designed to….

The module includes concepts, worksheets, and examples to help you assess your resources and preferences for successful start-up planning.

Participants will understand

-
-
-
-

Portfolio Pieces Developed in this Module

-
-
-
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Sustainable Farming Practices: Module 3 - Soil Management

Unit 1: Soil Fundamentals

1.1 Some Soil Fundamentals

As soils are transformed from rock or other parent material by physical, chemical, and biological reactions over long periods time, both their physical and chemical properties are changed. The five factors affecting soil forming processes include climate, organisms, parent material, relief, and time.

As described earlier, the resulting soils are composed of mineral and organic particles. The size distribution of the mineral particles is described by the soil textural class. The reactivity of the mineral components is a function of their size and composition. Smaller particles have greater surface area, and thus, capacity to interact with other particles, water, elements in the soil solution, and organic materials than larger particles. Composition of the mineral components also affects their chemical charge, or exchange capacity, with some clay-sized minerals having 10 to 20 times more capacity than others. Well-decomposed organic matter also has enormous surface area and exchange capacity, although its amounts in agricultural soils is usually 5% or less of the total weight.

The mineral particles interact with each other as well as organic matter under the influence of biological activity and varying environmental conditions. Over time these interactions result in stable aggregates of soil particles called soil structure. The soil structure in agricultural systems can in turn be strongly affected by management practices. The soil structure strongly affects aeration, water movement, and the ability of roots to explore and exploit the soil volume. Soil tilth, or the workability of the soil, and internal drainage are strongly affected by the texture and structure of soil layers.

The soil forming processes result in soils which are more chemically stable for the climate in which they formed. In warm, wet climates such as Virginia, soils undergo significant weathering. This means many of the minerals and elements present in the parent rock or material have been dissolved and leached away. What remains are highly stable minerals (low reactivity) such as quartz, iron oxides, and

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aluminum hydroxides, and new, more stable clay minerals have that have formed in place (secondary minerals). The resulting soils are acidic (pH is less than 7) and the clay minerals present have less charge (cation exchange capacity) than those found in neutral or alkaline soils. Soils with large amounts of quartz in the parent material typically have large particle sizes (sands), and low reactivity.

From an agricultural perspectives, the soils formed on a farm come with a suite of physical, chemical, and biological characteristics. Some of these, such as soil texture, are properties are inherent properties of the soil that are difficult or impossible to effectively change. Others, such as soil pH and nutrient status, soil organic matter content, and structure can be altered by management practices.

To better understand how management practices affect soil quality, lets first consider four key functions of soils in the agroecosystem.

1.2 Four Functions of Soils in Agriculture

Topics such as soil formation and the ecology, chemistry, physics, of soil are worthy of study in their own right. In their highly recommended book "Building soils for Better Crops", Magdoff and van Es encourage us, however, to "Think like a root!" From the perspective of farmer, soils serve four key functions. These are briefly described below, and these functions will be used to structure further discussion on soil based practices for sustainable production.

1.21 Soils provide a medium for plant growth.

Soils supply the basic mechanical strength to allow roots to penetrate and physically hold plants in place. The soil structure and chemical properties may either separately or together prevent seeds from emerging, or roots from penetrating to an adequate depth to provide structural support, water and nutrients. Shallow soils, extremely sandy soils, poorly structured clayey soils, or soils with root-limiting layers may not be suitable for agricultural production. On the other hand, soils with high percentages of sand, but with some silt and clay

Factors Affecting This Function

Physical

- Soil Strength to support plant canopy development

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- Not a real problem except in sandy or mucky soils subjected to frequent high winds.
- Blowing sands

- Provision of conditions for germination, emergence, growth and development
  - Soil to seed contact
  - Crusting
- Penetration of roots
  - Compaction and cemented layers
  - Coarse fragments
  - Shallowness
- Workability
  - Tilth, Texture, Structure
- Aeration
  - Water table management
  - Internal drainage
    - Very important for legumes reliant on soil air for N fixation
  -

Chemical

- Soil Acidity limiting root growth
- Salt accumulation or toxic elements limiting root growth

Practices Affecting This Function

- Tillage
- Erosion management
- Liming
- Nutrient management

1.22 Soils supply nutrients.

Soil colloids (very small particles) and organisms interact with nutrient elements, water, and the chemical environment of the soil solution in complex ways to retain and supply plant nutrients in accordance with plant demands. This capacity varies with the soil forming processes that shaped the soil as well as with the current and past management practices. The current fertility status of the soil can be assessed via soil testing for nutrients, pH, and organic matter content.

Factors Affecting This Function

- Plant Demand
  - In season
  - Stage of growth
  - Out of season

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- Soil solution nutrient concentrations
  - Total amount of each element present
  - Solubility
  - Soil water content
  - Soil pH
- Nutrient form(s) in the soil
- Retention capacity of the soil for nutrients (against loss by leaching)
  - Cation Exchange Capacity (CEC): a function of soil minerals and organic matter
  - Anion Exchange Capacity (AEC): a function iron oxides and aluminum hydroxides
- Degree of Aeration or Water saturation
  - Affects form and availability of some nutrients
- Organic matter: amounts, sources, and chemical composition
  - Must be mineralization by biological activity before plant uptake
- Immobilization of nutrients
  - Organisms compete with plants for available nutrients by capturing them within their biomass
- Plant Available N fixation through microbial sybiosis (legumes)
- Soil Acidity
  - Toxicity
- Temperature
  - Affects rate of root expansion and movement of nutrients

Physical

- Nutrients must be not only present, but "within reach"
  - Subsoil Sulfur
  - In-row bands of P fertilizers

Practices Affecting this Function

- Soil Testing
- Liming
- Cover Crops
- Nutrient Management
- Tillage Methods

1.23 Soils receive, retain, and supply water to plants

Soils receive rainfall, which either moves into the soil (infiltrates) or leaves the field as runoff. Once moisture enters the soil, it is either retained by soil surfaces and soil pores, or it continues to move through the soil, often taking nutrients in the soil water with it. The

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ability of the soil to hold water against the downward pull of gravity is called the (plant) available water holding capacity, and it varies with the amount of soil organic matter, and the proportion of sand (large particles), silt (flour-sized, fine particles), and clay (microscopic fine particles). The more organic matter, silt, or clay, the more water the soil can hold, and eventually resupply to plants. These same properties can also influence the ability of precipitation to infiltrate into the surface of the soil. The more soil organic matter, and in this case sand-sized particles, the greater the rate at which water can move into the soil, and the less that runs off the surface.

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Factors Affecting This Function

- Plant uptake rates of soil water
  - transpiration
- Precipitation
  - Runoff
  - Infiltration
  - Permeability
  - Leaching
- Available water holding capacity
- Evaporation
  - Temperature
  - Wind
  - Soil cover

Practices Affecting this Function

- Irrigation
- Cover Crops, Residues
- Tillage Methods

1.24 Soils provide a medium for soil organisms

Plant residues and soil organic matter provide carbon and energy sources for a host of organisms. Some interact with plants, others fragment or decompose dead tissue, and still others prey on other living organisms within the soil or nearby surfaces. These organism are affected and affect soil structure, soil acidity, and soil nutrients. Their activities form the basis for a number of ecosystem services which we as a society derive from soil ecosystems

- Nitrogen fixation by rhizobia, and blue green algae
- Nutrient cycling: N, S, C, P transformations
- Biocontrol of pests, mycorrhizae, natural enemies
- Pollination: many pollinators have an edaphic phase (soil dwelling) in life cycle

- Soil building: Structural generation and renewal, soil fertility renewal
- Bioremediation
- Provision of Clean drinking water
- Modification of the hydrologic cycle
- Erosion control
- Regulation of atmospheric gases
- Regulation of animal and plant populations
- Contribute to landscape heterogeneity and stability
- Habitat for production, recreation, natural history

Factors Affecting This Function

- Factors affecting all biological life
  - Water
  - Favorable chemical environment - esp soil pH
  - Aeration/Reduction
- Type and amount of OM
  - Heterotrophs: Carbon source for energy
  - Ability to attack and degrade
  - CN
- Biological interactions such as competition, symbiosis, predation, parasitism
- Host species
- Rotations
- Stratification:
  - soil organic matter decreases from surface with depth, creating different habitats

Practices Affecting this Function

1. Cover Crops and Residues
2. Nutrient Management
3. Tillage Methods
4. Rotations
5. Other conservation practices

Unit 2: Soil Degradation

Degradation most commonly occurs when erosion and decreased soil organic matter levels initiate a downward spiral resulting in poor crop production. Soils become compact, making it hard for water to infiltrate and roots to develop properly. Erosion continues, and nutrients decline to levels too low for good crop growth.

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2.1 Key Processes that degrade soils

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- Erosion
  - Typically removes the exposed surface soil. This is frequently the most valuable layer of the soil, containing organic matter, nutrients, and other past amendments to improve soil quality.
  - Affects not only soil quality, but when deposited in surface waters affects water quality and soil qual
- • Excessive tillage
  - breaks structural units
  - oxidizes organic matter
  - disturbs habitat for structure building organisms (e.g. Earthworms)
  - Reduces OM stratification
- Compaction
  - Tillage pans
  - Equipment traffic
  - Operations on wet soils
- Nutrient mining
  - Consistently removing more nutrients than are replaced
  - May be only one nutrient be overlooked (magnesium, potassium, or boron)
    - Hay removes very high amounts of K
- Nutrient Excesses
  - Lead to excessive leakage from the system, soils unable to retain within the system
- Leaching
  - Rainfall or irrigation in excess of the soil water holding capacity.
    - Don't forget that soils can retain significant amounts of water, not all of it needs to be replaced
    - over application of irrigation waters
- Salt accumulation
  - Although very rare in Virginia, it is possible to develop high salt concentrations in soils. Most frequently this comes about by use of water containing natural or fertilizer salts in excess of the capacity of rainfall or irrigation to leach them from the root zone.
    - This is most common in arid regions, but can also occur where natural rainfall is excluded, for example under a plastic mulch, inside a

non-moveable hoop house or greenhouse.

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Lets now consider each of the functions of soils in agroecosystems, and the practices affecting each.

Unit 3: Soil-based Practices

Plants need an adequate rooting media for structural support, air, water, nutrients and supporting services from soil organisms. In their highly recommended book “Building soils for Better Crops”, Magdoff and van Es encourage us to “Think like a root!”

The purposes of the practices we will discuss are to monitor and enhance these roles, so briefly introduce them here, along with some of the soil properties affecting them.

3.1 Tillage

3.11 Defining Soil Cultivation and Soil Tillage

- Cultivation: The total assemblage of tools and techniques used to develop and maintain soil fertility and crop production in garden and farm systems
- Tillage: The operation of implements through the soil to prepare seedbeds and root beds
- Tillage can drastically effect the soil habitat before cultivation consider the potential impacts on soil quality, biota, and structure. Climate, cropping system/crops, and soil conditions all influence timing and the type of tillage necessary.
- Over time, tillage can decrease soil OM matter, reduce biological activity and diversity, destroy aggregates, reduce nutrient and water holding capacity, loss of pore space, greater susceptibility to erosion.

Types of Tillage

- Primary tillage: Coarse and deep tillage that cuts, fractures, and mixes the soil. This is often accomplished with an implement such as plow, spader, chisels, offset discs, rotary tiller, lister plow that inverts, sifts, or mixes the top six inches to two feet or more of soil. Primary tillage is applied to soils in order to eliminate soil pans, incorporate organic matter and mineral soil amendments, incorporate cover crops and crop residues, and aerate soils.

- Secondary tillage: Shallow and fine tillage. Secondary tillage produces a fine seed or root bed by a series of operations that reduces the surface soil particle size. Secondary tillage tools and techniques are applied to the top 3 to 4 inches of soil and used to form fine, level, firm planting beds following primary cultivation. Secondary tillage employs disc harrows, spring- and spike-toothed harrows, and landplanes in the field, and forks and rakes in the garden.
- Until the last decade or so the standard tillage practice for corn was use of the moldboard plow for primary tillage followed by several secondary tillages and mechanical cultivation after the crop was up. Now about two-thirds of row crops are planted without use of the moldboard plow.
- Surface cultivation or cultivation tillage: Shallow, post-planting tillage used to loosen and aerate compacted soils, hill soil, and/or eradicate unwanted vegetation growing around cultivated crops. Cultivation tillage employs power incorporators and large rototillers, cutting knives and sweeps, and spring-toothed harrows.

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3.12 What are the advantages of Tillage?

Tillage has been an important part of agriculture for thousands of years. There are many good reasons to till.

- Soil conditioning: modies soil structure and tilth to favor agronomic processes (at least temporarily)
  - Primary: break large clods
  - Secondary: provide a quality seed bed
- Prevents or break up soil pans or compacted layers that reduce root penetration and yields
  - Plow pans
  - Traffic pans
  - Subsoil compacted layers
- Aerates the soil:
  - Promotes gas exchange of N2, O2, CO2
- Increases temperature of cold, damp soils in early spring
- Increases water infiltration (at least for a while)
- Enhances in-season mineralization of residues and soil-sequestered carbon
  - Increases pore space, decreases water
  - Increases biological activity
  - Incorporates (mix throughout root zone) organic matter, exposing it to more surface area, more organisms
  - Fragments residues

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- Incorporates non-mobile amendments throughout the rooting zone, enhancing chemical or nutrient availability status
  - Fertilizers such as phosphorus, potassium, calcium, magnesium, and micronutrients
  - Lime
  - Compost
  - Manures
    - Failure to incorporate manures results in volatile loss of much of the plant available nitrogen
- Improves management of high biomass crop residues and cover crops
  - Promotes release of nutrients in synchrony with crop demands
  - Enhances soil to seed contact, germination, and emergence
- Reduces populations in residue and surface dwelling pathogens and insect pests)
- Controls Weed in a timely manner
  - Annual weeds, seed bank management; preplant or during the season
  - Perennial weeds, continuously break crowns or rhizomes
- Creates specific seed and root beds to enhance productivity, ease of harvest
  - Plasticulture, double dug beds for asparagus, etc.
  - Many small seeded vegetables require precise placement of seeds, and excellent soil to seed contact for germination. This is not possible in soils with blocky structure.
- Retains soil moisture (dust mulch in dry-land farming)

More specific tillage objectives include seed bed formation, stale seed bed formation, compaction alleviation, fracturing of soil crusts, severing/dessication of weeds, maceration of biofumigant cover crops, stimulation of soil biology, and harvesting of root crops.

3.13 Land Preparation Equipment

- Tractor: a traction machine that provides mechanical, hydraulic, and/or electrical power to implements to perform a wide range of crop production and handling operations. Tractors are most often used to perform drawbar work (pulling equipment through the field) and PTO (power take-off) (power to rotate equipment components) work. Tractors can be equipped with rubber tires, rubber belts, or steel tracks. A

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modern farm tractor is almost always equipped with a diesel engine and tractor size is measured by the amount of power that the tractor can produce at the PTO. Tractor sizes range from those with less than 40 PTO horsepower to ones that produce more than 400 horsepower. The cost of a large modern tractor can be well over $200,000

- Plow - an implement used to perform primary tillage. A number of types of plows are in common use including the moldboard plow, the chisel plow, and the disk plow.

The moldboard plow has a large frame that is equipped with a series of "bottoms," each of which consists of a steel coulter to slice through residue followed closely by a steel share that cuts the soil and an attached moldboard that is used to raise and turn over the cut "slice" of soil.

Disk plows work in a similar manner to laterally displace and invert soil through the use of concave steel disk blades.

Chisel plows use curved shanks to penetrate and "stir" the soil without inverting a soil layer. Chisel plows cause less residue disturbance than moldboard plows and are often used in conservation tillage systems.

- Disk Harrows (or Disk) - are implements that uses steel blades to slice through crop residues and soil. Disk blades are mounted in groups or gangs that rotate as they move forward through the soil. Front gangs move soil toward the outside of the disk while rear gangs move soil back toward the center of the disk. A disk can be used for primary or secondary tillage.
- Field Cultivator -an implement used to perform secondary tillage operations such as seedbed preparation and weed eradication. Field cultivators are equipped with steel shanks that are typically spring mounted to permit the shank to move within the soil and shatter clods. Field cultivators are constructed similarly to chisel plows, but are more lightly built. Large chisel plows can exceed 50 feet in width in the field.

(See the NRCS Pocket Guide, and the the SARE Steel in the field references. Both are available as downloadable pdfs).

3.14 Factors Influencing Timing and Type of Tillage

- Soil Moisture

Tillage should take place only within the soil moisture range of 50–75% of field capacity. Tillage executed at soil moistures higher than 75% of field capacity can increase soil compaction, or the compression of both pore spaces and soil aggregates. Soil tillage undertaken when soil moisture is below 50% of field capacity may pulverize soil aggregates, resulting in poor soil structure and increasing the risk of soil erosion.

- Soil Texture and Classification:

Sandy soil: Sandy soils with relatively large particle size and large pore spaces are often naturally well drained, aerated, and friable. These features, combined with the relatively inert nature of the sand particles, lead to soil conditions in which organic matter oxidizes rapidly and unstable soil aggregates form. Though less susceptible to compaction when tilled outside of the ideal moisture range, tillage systems in sandy soils must generally be conservative in order to retain soil aggregates and maintain desirable physical properties.

Clay soil: Soils with a high percentage of clay (>40%) have many micropore spaces and often exhibit poor drainage and gas exchange characteristics. Clay soils often require an extended period (5–7 or more years) of frequent, deep tillage in order to incorporate adequate amounts of mineral soil amendments and organic matter to create the desirable physical conditions resulting from the stimulation of soil biological activity. Clay soils must be worked at optimal soil moistures (50–75% field capacity) to avoid creating clods—large and compacted soil masses—that lead to soil physical properties of poor quality.

- Climate

Temperature, evaporation, and precipitation strongly influence soil development, so that Arctic, tropic, temperate, and arid regions all tend to develop different types of soil. Temperature, evaporation, and precipitation influence the degree and duration of soil biological activity, which in turn determines the mineralization rates of soil organic matter and the degree of organic matter accumulation in a given soil. Generally, the greater the number of days with soil temperatures below 50ºF and the higher the annual amounts of precipitation, the greater the accumulation of soil organic matter

- Cropping Systems

Annual cropping system: Annual cropping systems feature intensive cropping of nutrient-demanding plants, which necessitates a high frequency of soil tillage, resulting in both organic matter and plant nutrient losses. Annual cropping systems demand high inputs of organic matter and mineral amendments to counter losses.

Perennial cropping system: Perennial cropping systems require little or no tillage after initial planting and demand only periodic surface cultivation or mowing to manage competing

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vegetation

- Soil Condition

Soils of good tilth: Soils with well-developed physical and chemical properties often less extensive tillage and are maintained by incorporating soil amendments into the top 4–12 inches of soil. The physical properties of such soils should be monitored and, when necessary, periodically deeply tilled to disrupt soil compaction and incorporate organic matter soil amendments, which encourage soil aggregate formation.

Soils with physical properties of low quality: Untilled ground and soils with surface or sub-soil compaction are initially deeply tilled each year, using double digging on a garden scale and mechanical spading or chisel plowing on a field scale. This deep tillage—combined with planting deep-rooted cover crops—fractures compacted soil layers and distributes soil amendments throughout the soil profile, encouraging development of soil aggregates and reducing soil bulk density. Once the physical properties of the soil have been developed/improved, less intensive tillage techniques may be used for maintenance purposes.

3.15 So Why the Push for No-Till?

- Most importantly, tillage can leaves the soil surface vulnerable and unprotected against the erosive forces of water and wind, increase surface runoff, and decrease infiltration of water into the soil profile.
- Tillage can decrease soil OM matter by enhancing oxidation, thus leading eventually to reduced biological activity and diversity, reduced nutrient and water holding capacity, and loss of pore space.
- When viewed from the standpoint of the soil habitat, tillage is a very disruptive practice. Instead of stratified horizontal layers rich in recently added organic matter at the surface and decreasing with depth (creating many types of habitat for soil organisms), residues are incorporated and distributed uniformly throughout the tilled soil.
- This process not only disrupts soil structural aggregates, but disturbs the habitat of organisms such as earthworks, springtails, and other organisms that feed on surface residues.
- Surface crusting can be enhanced lowering the surface organic matter, and pulverization of soil aggregates

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- Subsoils can be compaction by tillage implements if the soil moisture level is not ideal during tillage
- Tillage increases labor, fuel, equipment and maintenance costs
- Where residues are incorporated, tillage can increases evaporative loss of soil water
- Rocks can be brought to the surface by tillage

3.16 Is it possible to raise crops without intensively tilling the soil?

Yes! But not every situation is appropriate for no-till methods. Various forms of reduced or no-till have been proven effective in Virginia. The two primary concerns are managing weeds without tillage, and getting a good stand, particularly with small seeds, when planting into thick residues on the soil surface. Very effective no-till planters are now available that are able to cut through residues, form a slot in the soil, place the seed in the slot, and then press the soil back in place to achieve good soil to seed contact. Many field crops in Virginia, including corn, soybean, small grains, cotton, and sorghum are now planted into residues of the previous crop, a killed (with herbicide) cover crop, or a smother crop. (A smother crop is a tall cover crop or stems of harvested small grains which are mowed and left in place or knocked over with crimping roller, a larger roller with blades that crimp the plant stalks to prevent them from standing back up and shading the soon to emerge seedlings). Crops that are resistant to certain herbicides can be safely treated after the crop emerges, killing the weeds but not the crop. In production systems that do not use herbicides, planting higher plant populations to increase crop competitiveness, and the use of between-the-row, shallow cultivation can reduce weed pressure. This is a reduced-tillage rather than a no till system, but can result in over 30% of the surface remaining covered with residues, a level that protects against erosion during most rainfall events.

When compacted zones beneath the surface form due to heavy equipment in the field or due to prior tillage, chisel plows can be used to break up compaction while disturbing only a narrow band of the soil. This can be an important method of tillage for crops such as small grains and cotton whose roots do not penetrate well in compacted soils. Deep subsoiling shanks that resemble large fishhooks can be used immediately ahead of the planter to break up the soil to a depth of 12 to 14 inches directly beneath the row.

3.17 Minimum Tillage Systems

Types

- Conservation Tillage: Use fewer operations; leave 30% or more of crop residues on the surface after planting.
- Rip or Strip till: a ripper, or chisel may precede the planter to break up soil compaction (especially small grains)
- No-till: Minimal preparation of seed bed, only opening of soil is for planting furrow for seed

Advantages

- Reduce SOM losses (generally increases)
- Reduce soil erosion
- Conserves energy (fossil fuel)
- Saves time and labor inputs

Disadvantages

- Less aeration and warming in the spring

Can shorten already narrow windows for growing season

- Reduced nutrient availability until soils warm
- Can increase vertebrate pests and slugs
- Weed, disease, and insect pressures must be dealt with in other ways

often pesticides or hand labor only viable options

- Special planting equipment is be required
- Frequent disturbance and disruption of habitat for large soil fauna especially worms
- Very challenging on poorly drained soils
- Can reduce yields of small grains planted in the fall without tillage. These crops are very sensitive to compaction and cool season growth exacerbates the problem.
- There can be a transition period in which yields are decreased. No till affects many aspects of weed, pests, and disease that must be integrated into a systems approach.

3.18 Summary

- Till with care, and with your objective(s) clearly in mind. Choose the best implement for the job, and avoid tilling when the soil is too wet (causes compaction and degrades structure) or too dry (pulverizes soil, increases dust and wind erosion). Turn-plowing (moldboard) too deeply buries the biologically active topsoil under a layer of subsoil, which disrupts the soil food web and reduces fertility. To break sod, adjust the plow to work no deeper than 6 – 8 inches, and to partially invert furrow slices to allow sod to decompose aerobically.
- Chisel plowing can fracture hardpan and break sod without

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inverting the soil profile. Disk harrows and rotary tillers are used to prepare a seedbed. Frequent or intensive tillage with any implement burns up soil organic matter, kills off beneficial soil fungi and earthworms, and promotes erosion. Rotary and reciprocating spaders (to incorporate residues and prepare a seedbed) and light duty cultivation implements such as torsion weeders and finger weeders are gentler on the soil than some of the older tillage and cultivation tools.

- Reduce tillage when practical. Maintain living plant cover or substantial residue or mulch coverage for as much of the year as practical. Use steeper slopes (above 7%) for pasture, orchard, or other perennials that do not entail annual tillage or cultivation.
- Continuous no-till systems generally require the use of contact herbicides to kill weeds. However other forms of conservation tillage, such as mulch till, ridge till, and rotational no-till, can be done without herbicides. Rotational no-till entails terminating a high biomass cover crop by roll-crimping or mowing, which leaves a weed-suppressive mulch into which the cash crop is planted without tillage. After harvest, some tillage is performed to control weeds and prepare a seedbed for the next cover crop.

- **3.19 Resources**

- NRCS Tillage Equipment Pocket Guide: ftp://ftp-fc.sc.egov.usda.gov/IA/intranet/Tillage.pdf (A 78 page booklet with pictures of tillage equipment and tillage action).
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- Steel in the Field: A Farmers Guide to Weed Management Tools, Published 2001, 128 pages. http://www.sare.org/publications/steel/steel.pdf
-
- Kuepper, George. 2001. Pursuing conservation tillage systems for organic crop production. ATTRA's Organic Matters Series. Fayetteville, AR: ATTRA – National Sustainable Agriculture Information Service. www.attra.org/attra-pub/organicmatters/conservationtillage.html
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- Magdoff, F., and H. Van Es. 2000. Chapter 15: Reducing tillage. In Building Soils for Better Crops (2nd Edition). Handbook Series Book 4. Sustainable Agriculture Network. Beltsville, MD: National Agricultural Library. www.sare.org/publications/index.htm
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- Magdoff , Fred, and Ray R. Weilm (eds.). 2004. Soil Organic

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Matter in Sustainable Agriculture. Advances in Agroecology Series: Volume 11. CRC Press. (See especially Chapter 8.)

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3.2 Essential Elements and Soil Testing

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The first focus of a farmer is to provide adequately for the crops to be grown. It is essential to know which elements are required. The more you understand about how these nutrients interact with the soil, the better your soil nutrient practices will be. An excellent starting point is assessing the soil fertility status with a soil test.

Plants require at least 18 different chemical elements to grow and yield. They obtain carbon (C), hydrogen (H), and oxygen (O) from air and rainfall, and rely on the soil for all other essential elements: nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg); and the trace elements required in small quantities: copper (Cu), zinc (Zn), manganese (Mn), iron (Fe), boron (B), molybdenum (Mo), sodium (Na), nickel, (Ni), and chlorine (Cl). Of these, N, P, and K are most often deficient or yield-limiting, although S, Mg, and micronutrient deficiencies can also occur. In Virginia, B is the most common micronutrient deficiency, and yield-limiting Mo, Mn and Zn levels can also occur.

3.21 What is Soil Testing?

- Soil testing gives you an indication of the soil acidity or alkalinity and the amount of nutrients available for plant uptake during the growing season.
- Soil nutrient (or fertility) testing is a predictive tool based on in-field studies of many crops and their ability to extract nutrient in plant available forms from the soil. A solution is added to the soil sample, allowed to react, and then extracted and analyzed in an attempt to estimate the amounts of plant available nutrients. The results are then compared with amounts actually extracted by different crops in research fields having various nutrient levels. The results are used to predict both the relative fertility status (low, medium, high, very high) and the amount of nutrient additions required to overcome any deficiencies and to build the soil nutrient supply.
- Since soil testing focuses on plant available, soil-bound nutrients, and is calibrated against actual plant performance in the field, the results are useful for both conventional and organic production methods. However, the recommendations may be used differently. Unless soils test are low, organic producers frequently rely less on inputs of (approved) minerals, and more on soil life to release plant available forms from applied compost, manure, and other

inputs to build soil fertility in low testing soils, and to replenish the amounts removed in harvested crops. Translating soil test results into organic or ecological nutrient management approaches can be challenging, but is a skill that can be learned. Both organic and conventional production systems use agricultural limestone to raise soil pH, elemental sulfur to lower pH, and small quantities of micronutrient salts or chelates to address micronutrient deficiencies.

- Soil testing analyses are conducted by Virginia Tech and several private labs, and typically include pH, P, K, Ca, Mg, Cu, Zn, Mn, Fe, and B. Analysis of soluble salts and soil organic matter are usually available.
- It is strongly recommended that you conduct soil tests before putting new or unfamiliar fields into production. Testing should be repeated every two to three years to evaluate trends and responses to management practices and inputs. The best time for sampling is in the fall of the year after harvest. This allows plenty of time for results and planning before the busy spring season.
- Soil tests rarely report N per se, because levels of crop-available N (nitrate + ammonium) fluctuate almost daily depending on soil biological activity, rainfall, and plant uptake, making meaningful interpretation impossible. This is particularly true for samples taken in the fall to predict needs the following spring.
- Note that soil testing laboratories assume "normal" conditions when rating sample results. If soils are seriously degraded, (compaction, poor aeration, low organic matter, or low pH) root growth and uptake will suffer, and plants may well experience nutrient deficiencies.
- Conversely, you may find that for your soil and management system, lower amounts of nutrients can maintain your soils at a highly productive state, particularly where high amounts of organic matter are returned each year and nutrients removed in the harvested crop are faithfully replaced.
- Supplement soil testing with your own observations over time, keeping record of yields and soil test levels. These observations should include yields and measures of soil quality.
- Crop foliar analysis (or tissue testing), can be used to show what nutrient conditions the crop has experienced over the last few days to weeks. Although not a predictive test, it can be a very valuable too for identifying difficult to analyze deficiencies, or for assessing the effectiveness of your nutrient practices to that point in the season. Tissue testing is particularly useful for

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tree crops which feed much differently than annual crops.

3.22 Considerations for Taking Soil Samples

- Don't wait until the last minute. The best time to sample for a general soil test is usually in the fall. Spring samples should be taken early enough to have the results in time to properly plan nutrient management for the crop season.
- Be consistent on your sampling time from year to year. There are normally subtle shifts shifts, particularly in pH, from season to season within the year. In order to compare values from year to year, try to sample at around the same time. Also note that different laboratory may use slightly different procedures, so you are better off to use the same laboratory if you intend to track results across years.
- A field or sample unit should include only areas in which lime and nutrient applications (including organic byproducts)have been managed the same in the past. Take separate samples from problem areas if they can be treated separately.
- Use a soil sampling probe or small shovel to take small uniformly sized samples from 10 to 20 random locations in each field or sampling unit. Mix together in a clean, plastic (not metal) bucket to create a single "representative sample". Air dry if possible. About one cup of soil will be required by the lab.
- For fields that have been tilled, sample to a depth of six inches. For un-tilled fields and perennial pastures, sample to a depth of four inches.
- Complete the information sheet, giving all of the information requested. Remember, the recommendations are only as good as the information supplied.
- Sample fields at least every three years and at the same season of the year each time. On higher-value crops annual soil tests will allow you to fine-tune nutrient management and may allow you to reduce nutrient inputs.

3.23 Beyond soil testing

- Supplement soil testing with your own observations of soil quality such as tilth (ease of working, visible aggregation or crumb structure), degree of surface crusting or subsurface compaction, abundance of earthworms and other macroscopic soil organisms, ability of the soil to absorb rainfall without ponding or runoff, and soil moisture retention during dry spells. A penetrometer (compaction tester) can be useful for

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detecting a subsurface hardpan that may restrict root growth, causing crop nutrient deficiencies when soil nutrient levels are sufficient.

3.24 Resources

Magdoff & Van Es – Chapter 21 (soil tests)
Chapter 22 (field and lab evaluation of soil health).

How to Use a Soil Test – VABF info sheet, 4 pp

Soil testing at Virginia Tech
http://www.soiltest.vt.edu/

3.3 Nutrient Management

3.31. Goals of Nutrient Management

Besides maintaining soil health, the goal of a nutrient management plan should be to meet a crop's nutrient needs as economically as possible while avoiding application of excess nutrients.

- Crop production and harvest consumes substantial amounts of N and K, moderate amounts of P, S, Ca, and Mg, and small amounts of Cu, Zn, B, and several other micronutrients. Because plant-available soil N, P, and K are most often limiting to crop yield, conventional fertilizers are formulated to deliver these three elements. Recommended application rates, which are based on research into crop yield responses, often exceed the amount actually removed in harvest. As a result, surpluses may remain after harvest. Excess nitrate-N can leach into ground water and excess P may be carried by runoff into surface waters, resulting in nutrient pollution. Surplus K may also leach or run off, but is considered non-polluting.
- Water quality concerns related to N and P in animal manures and agricultural fertilizers have led to the development of nutrient management protocols based on federal and state level regulations to protect aquatic ecosystems. Soluble fertilizers and manure are the most common sources of nutrient pollution of ground and surface waters. Some other organic N inputs, such as a succulent, all-legume green manure, can contribute to N leaching. As noted by Magdoff and van Es (Building soils for better crops, page 209) just using cover crops and organic sources does not guarantee that you are not building excess nutrients in the soil and releasing them

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to the environment.
- Fertilizers and other nutrient inputs entail direct costs to the farmer as well. A sound nutrient management plan is good business practice as well as good resource stewardship.
- Nutrient management is an integral part of promoting soil health through good physical, biological, and chemical properties. We have noted that the key to building soil health is organic matter management. Building up and maintaining soil organic matter contributes to nutrient management through better soil tilth and thus root exploration, enhanced biological activity which increases mineralization and nutrient availability, and greater cation exchange capacity which enhances nutrient retention. Soil organic matter also promotes an abundance of microorganisms that can stimulate root growth and help solubilize nutrients. A second key component is managing the soil pH through soil testing and lime application. This enables good biological activity, root growth, and optimizes the availability of a wide range of nutrients.
- Managing soil nutrients, or chemistry, should not be separated from management of the physical and biological condition of soil. A good nutrient management program supports and improves all three aspects of soil health, since they are interrelated.

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3.32 Plants and Nutrients

What nutrients do plants need in order to complete their life cycle (germination, emergence, vegetative development, reproductive development, successful reproductive structures)?

- Plants must have access to adequate amounts of 18 elements in order to complete their life cycle including germination, emergence, vegetative growth, and reproduction.
- An inadequate supply of any one of these will limit the yield or quality of the crop.
- Focus is generally placed on nitrogen, phosphorus, and potassium since these are used in large amounts by plants, and their absence strongly affects yield and quality.

What happens when elements are deficient?
- Nutrient deficiencies usually affect the plants ability to produce photosynthate or to partition it to reproductive tissues. Yields and or quality are almost always reduced.

- Environmental Impacts: a nutrient deficiency limits the ability of plants to use other nutrients available in the soil. For example, a phosphorus deficiency could result in very poor growth, and essentially no uptake of nitrogen. Poor growth may also expose the soil to erosion.

How can I know if levels are adequate or excessive in the soil?
- Soil testing is an extremely useful tool for assessing soil deficiencies of nutrients except N, S, and Mo. Levels of these nutrients change rapidly in soils, and are not routinely included in soil testing protocols.
- Soil testing can also tell you when nutrient levels are exceeding the needs of plants (soils testing very high). Of particular concern is Phosphorus
- Nitrogen availability must be estimated from previous experience, management practices, and prior crops. Mineralization of soil organic matter may provide 20 to 40 pounds of N for sandy soils with 2% organic matter content while soils planted to mature, plowed down legume cover crops may supply 120 to 150 pound of N.
-

Do various crops require different amounts of nutrients?
- Nutrient demands, especially N, vary considerably from crop to crop (See Table 1).

0 N for legumes: high N concetntation actually inhibit nodulation

170 lbs N per ac for sweet corn, 220 for field corn

200 or more for potato, 130 for tomato

70 for squash, oats, cotton

- Excessive N in crops with low demand can result in poor fruit set, poor quality fruit
- The amount of each element required is particular to each species, and to a lesser extent, cultivars within a single species.

Legumes require little or no soil-derived N, higher P, more B and Mo

Cereals require more added N, K, and can absorb excess amount

Table – Did not translate to Word. Wll redo

Does nutrient uptake vary during the growing season?
Plants generally take up small but essential amounts of nutrients early in the season, then enter a period of rapid growth with high daily nutrient

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demands. These nutrients are stored within the leaves. As the plant begins to mature, growth and uptake slow, and nutrients begin to move toward the reproductive tissues. These flows come from both soil uptake and nutrients stored in the leaves.

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3.33 Nutrient Forms and Fate in Soil

What form of nutrients are taken up by soil organisms and plants?

- Organic and mineral forms may be consumed and used by soil organisms
- Only mineralized forms of nutrients are taken up by plants. (Soluble cations and anions)
- These ions are taken up by plant root systems primarily from the soil solution.

What happens to soluble nutrients in the soil solution?

- Mobility Is important: Mobile forms of nutrients are readily lost from the soil when excess water moves through the soil (leaching). The charge of the ion and its amount determines how strongly it is held by the soil clays and organic matter.

Cations (positively charged) are retained by negative charged soil colloids (the cation exchange capacity). These include ammonium, calcium, magnesium, potassium, and most micronutrients.

Anions (negatively charged) are not readily retained by the soil, and are subject to move with the soil water. These include nitrate-N, sulfur, molybdenum, boron, and chlorine.

Highly reactive ions: phosphate, an anion, is highly reactive with iron and aluminum in the soil. Only when it is present in very large amounts does it begin to leach with the soil water and become a potential pollutant.

- Nutrients may be used by soil organisms
- Nitrogen in the nitrate form may be biologically converted to a gas (denitrified) and lost to the atmosphere
- Non-mobile nutrients bound to the soil can be lost through erosion
- Runoff – mobile elements present in the soil solution near the soil surface can be carried away by water moving across the surface of the soil
- Some elements may form solids when present in high concentrations
- Nutrients may be taken up by plants and removed with harvested products

It is important to be aware of the amounts of nutrients removed in the harvested products. Failure to replace these nutrients (or monitor them by a good soil testing program) will result in nutrient mining and soil degradation.

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For more information on nutrients removed in harvested crops http://www.soil.ncsu.edu/publications/Soilfacts/ag-439-16W.pdf.

3.34 Nutrient Cycling

If organic matter remained as organic matter, where would we be? How is organic matter transformed into nutrients available for plant use?

Crop residues usually average 40% carbon, and this figure doesn't change much from plant to plant. On the other hand, nitrogen content varies greatly depending on the type of plant and its stage of growth.

The ratio of the amount of a residue's carbon to the amount of its nitrogen influences nutrient availability and the rate of decomposition. The ratio, usually referred to as the C:N ratio, may vary from around 15:1 for young plants, to between 50:1 and 80:1 for the old straw of crop plants, to over 100:1 for sawdust. For comparison, the C:N ratio of soil organic matter is usually in the range of about 10:1 to 12:1, and the C:N of soil microorganisms is around 7:1. The C:N ratio of residues is really just another way of looking at the percentage of nitrogen.

When the C:N ratio of an added organic source is high, soil organisms will attack the carbon as an energy source, releasing excess nutrients, and multiplying rapidly. To do so, they must pull N from the soil around them to build new cells and reproduce (recall C:N=7 for soil organisms). The process of storing nutrients in the microbial biomass is called immobilization. Plants growing in this environment will have a difficult time finding plant available N.

As the carbon source declines, organisms die, are in turn decomposed, and release nutrients back into the soil solution. For organic sources with a low C:N ratio (legumes), nitrogen will be quickly released during the process of mineralization.

Key Processes

- Immobilization

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- Mineralization
- Biological Activity and Chemical Activity: Rates depend on
  Temperature
  Moisture
  Soil solution pH
  Presence of appropriate biological agents
  The physical presence of reduced carbon (SOM)
  The chemical characteristics of the carbon source
  C:N Ratio; C:N:P ratios.
  C:N < 20 organisms degrade OM easily, releasing mineralized N
  C:N >20 organisms retain N and attack C and N containing compounds

- How much N can be mineralized from soil organic matter?
  A rule of thumb is about 30 lbs of N per acre per year for every 1% of soil organic matter.
  This will vary with the temperature, soil water, tillage and incorporation, as well as the C:N ratio, and other features of the organic source.

3.35 Characteristics of Sources

A. Cover Crops
Cover crops are at the heart of supplying essential nitrogen for those who wish to avoid commercial fertilizers, or who wish to reduce use of expensive sources of N. Rotations that include nitrogen fixing cover crops have many benefits (See 3.4 Cover Crops), but from a nutrient management standpoint, the most important is the relatively low cost of nitrogen obtained through biological fixation by leguminous cover crops.

Table 3. Plant Available N supplied by cover crops.

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Previous Crop Nitrogen Credit	Lbs N per acre
Grass sod	20
"Fair" clover (20-60% stand)	40
"Good" clover (60-100% stand)	60
"Fair" alfalfa (20-60% stand)	60
"Good" alfalfa (60-100% stand)	100
Sweet corn stalks	30
"Good" hairy vetch winter cover crop	100
Corn stover after grain harvest	40

From: Vern Grubinger, Nutrient Management on Organic Vegetable Farms, Univ. Vermont. Coop. Extension.

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Non-legume covers are especially important in trapping nutrients remaining unused after a harvest, and in protecting the soil when no cash crop is growing. In general, these crops are not fertilized if their purpose is to reduce nutrient loss and to prevent erosion. Studies in North Carolina indicate that about 15% of the N taken up by cereal cover crops will be mineralized and available for plant uptake in the season after the cover is killed (M. Wagger, personal communication).

A potential concern with using cover crops as an N sources is synchronizing the release of nutrients from a the cover crop with peak demand by the crop. As shown in Figure 1, the amount of N contained in a cover crop is a function of its maturity (time of season). In addition, the cover crop must undergo the process of mineralization by soil organisms. The resulting release of nutrients should be timed to correspond with the N demand of the cash crop.

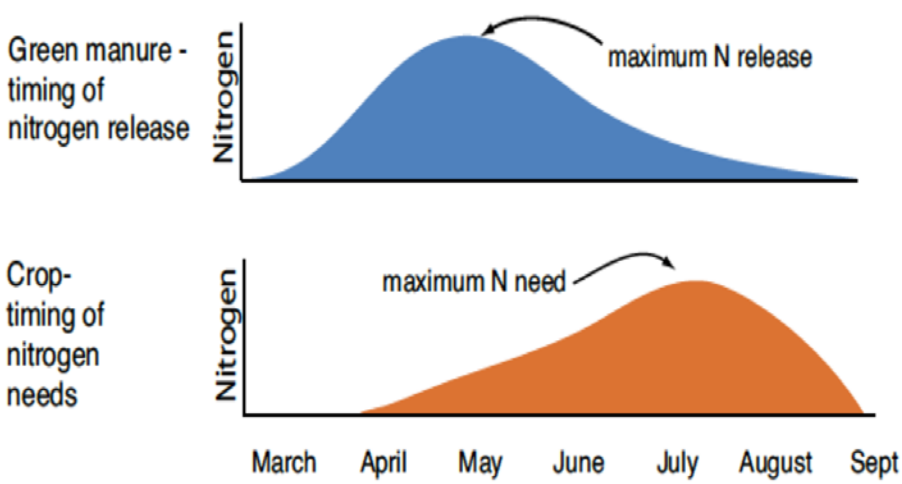

Figure 1. Generalized diagram of nutrient release from green manures relative to crop needs. From "Risk management for Organic Producers.

[Note several universities publish lists of nutrients, especially N, provided by use of cover crops. If you need addition information, check out the publications on cover crops from then Center for Environmental Farming Systems at NC State, or at Penn State University.

B. Animal Manures

Nitrogen in manure occurs in three main forms: ammonium. (NH_4+), urea (a soluble organic form, easily converted to ammonium), and solid, organic N. Ammonium is readily available to plants, and urea is quickly converted to ammonium in soils. However, while readily available when incorporated in soil, both ammonium and urea are subject to loss as ammonia gas when left on the surface under drying conditions. Some manures may have half or three-quarters of their N in readily available forms, while others may have 20% or less in these forms. Manure analysis reports usually contain both ammonium and total N (the difference is mainly organic N), thus indicating how much of the N is readily available—but also subject to loss if not handled carefully.

As with any organic source containing multiple nutrients, the amount applied can be based on only one priority nutrients. All the others are applied major problem encountered with manures and other organic forms of nutrients is that the nutrients come as a package. If applying manure to meet the N requirements of a crop, too much P and K are usually applied. If applied at a rate to meet the P needs (or in the Chesapeake Bay region, the restrictions) too little N and K may be applied. All to often, manures are applied at rates exceeding plant requirements. Amounts visible to the human eye after application generally indicate applications well in excess of 10 tons/ac.
The NOP rules on manures use include the following restrictions:
1. No raw manure unless it is incorporated more than 120 days prior to harvest for crops for human consumption whose edible portion is in direct contact with the soil.
2. No raw manure unless it is incorporated more than 90 days prior to harvest for crops whose edible portion does not contact soil.
3. Biosolids (human-derived municipal wastes) are not allowed.

Table 4. Typical Plant available nutrient contents of animal manures.

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	N (%)	P_2O_5 (%)	K_2O(%)	Mg(%)	Relative Availability
Dried poultry manure	4	3	3	0	med
Manure (fresh)					
Dairy	0.5	0.2	0.5	0	med
Horse	0.5	0.2	0.5	0	med
Sheep	1	0.5	1	0	med
Poultry (broiler)	3	3	2	0	med/rapid

For more information see Building Soils for Better Crops, Chapter 12 "Animal manures for increasing organic matter and supplying nutrients", pages 129-138.

For more information see Building Soils for Better Crops, Chapter 12 "Animal manures for increasing organic matter and supplying nutrients", pages 129-138.

C. Compost

The composting process results in a dark-brown material in which the initial constituents are no longer recognizable and further degradation is not noticeable. The final product is much more pleasant to use and more compact to handle than the original materials. The length of time needed to achieve finished compost will vary with many factors and can take anywhere from a couple of weeks to over a year.

Application of an unfinished, carbonaceous compost could affect plant growth adversely since the compost may have its own demand for nutrients as the breakdown to maturity continues in the soil. In addition, immature composts made from nitrogen-rich feedstocks (i.e. poultry manure) are often high in ammonium which can be toxic to plant growth.

Finished compost is a dilute fertilizer, typically having an analysis of about (1-1-1 N-P2O5-K2O). This varies with original materials that were incorporated into the pile and how they were composted. The majority of the nitrogen in finished compost (usually over 90%) has been incorporated into organic compounds that are resistant to decomposition. Rough estimates are that only 10% to 30% of the nitrogen in these organic compounds will become available in one growing season. Some of the remaining nitrogen will become available in subsequent years and at much slower rates than in the first year.

While additions of compost can supply low N demand crops, its use for high N demand crops will almost invariably result in too little N (lost yield or quality) or large excesses of P and K. Organic producers should consider the use of legume cover crops to supply N for higher demand crops.

For more information, see Building Soils for Better Crops, Chapter 13, "Making and using composts", page 141-149.

D. Purchased Fertilizers

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Sellers of all fertilizers in Virginia (organic or synthetic) must label and guarantee the plant available nutrient content of the materials they sell. Regulations and random testing ensure that the advertised values accurately reflect the content. The grade, such as 1-1-1 or 10-10-10 presents the percentage of plant available N, P2O5, and K2O in the fertilizer. Other nutrients listed on the label must state the guaranteed content and, in some cases (micronutrients), the source.

Organic fertilizers are usually processed organic byproducts (bonemeal or bloodmeal), unprocessed mineral powders, or blended from composted manures, sometimes with the addition of approved organic nutrient sources to ensure guaranteed nutrient concentrations. One exception is Chilean nitrate of soda, which is a form of sodium nitrate naturally produced from the droppings of birds or bats. The continued use of this source for certified organic operations is currently under review. The guaranteed (plant available) nutrient concentrations of organic fertilizers are typically much lower than commercial sources, and the costs per unit of plant available nutrient is much higher. In some cases, these sources have additional nutrients (Total N, Total P) included which are not guaranteed since they are not water soluble.

Table 5. Fertilizers approved for organic production. Typical Nutrient Content (by Weight) of Organic Materials (Nutrient content varies). (Source: http://www.nevegetable.org/index.php/cultural/guidelines)

	N (%)	P_2O_5 (%)	K_2O(%)	Mg(%)	Relative Availability
Alfalfa meal	3	0.5	2.5	0	slow/med
Blood meal	12	1	0.5	0	med/rapid
Bone meal (steamed)	3	15	0	0	med
Bone char	0	32 (16 avail)	0	0	med
Cottonseed meal	6	2	2	0	slow/med
Feather meal	12	0	0	0	med
Fish emulsion	5	2	0	0	rapid
Fish meal	9	7	0		
Bat guano	6	9	2	0	med
Peanut meal	8	1	0	0	slow/med
Soybean meal	7	2	2	0	slow/med
Wood ashes	0	2	5	0	rapid
Colloidal phosphate	0	20*	0	0	very slow
Granite dust	0	0	4	0	very slow
Green sand	0	1	7	0	very slow
Rock phosphate	0	30**	0	0	very slow
Chiliean nitrate***	16	0	0	0	rapid
Sul-Po-Mag	0	0	21	11	rapid
Epsom salts	0	0	0	10	rapid
Dolomitic lime	0	0	0	10	med
Potassium sulfate	0	0	52	0	rapid

* about 3% available
** about 2% available
*** Chilean nitrate is currently restricted and is expected to be prohibited after October 2012. Check with your certifier.

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Synthetic or Commercial fertilizers are manufactured from processing of mined resources of minerals (P, K, Ca, Mg, S, micronutrients), or from processing of fossil fuels. Nitrogen comes primarily from combining natural gas (for the H content) with air (for the N content) at high temperature and pressure. This process results in ammonia, NH3, a gas that is then either liquefied (under pressure) and used directly, or is combined with other reactants to produce urea, ammonium sulfate, ammonium nitrate, or aqueous mixtures of urea-ammonium nitrate fertilizers. Commercial fertilizers contain relatively high nutrient concentrations, and the values reported are plant available. Ammonia is a toxic gas and requires special equipment and practices for safe and effective application. Ammonia has a very high initial pH (>10) and the gaseous form is toxic to many soil organisms and to young plants. As it undergoes ammonification and nitrification, the soil can also be strongly acidified. Many of the negative comments attributed to commercial fertilizers are based on the characteristics and resulting reactions of this compound, even though they may not apply to other fertilizers. This fertilizer source is heavily used in corn production in the Corn Belt, but is not common in Virginia. Urea, a synthetic organic form of N is the most common source of N in the region. This source is broken down by a common enzyme (urease) into ammonia. When not surrounded by soil or in contact with soil water (sitting on the soil surface, or on plant leaves), some volatile losses may result.

Manufactured fertilizers with high nutrient contents (Table 6, below) and relatively high solubility can dissolve and increase salt concentrations if placed too near the seed or plant root system. Users should be aware of the potential for salt injury of seeds in young plants. This is most critical in soils with inherently high salts already. In Virginia, growers sometimes apply fertilizers directly in the row with seeds at planting, but should not apply more than 100 pounds of a fertilizer material per acre in this manner if they wish to avoid salt damage. Mixing of the material with the soil or band placement some distance from the seeds (usually 2 inches beside and below) can prevent salt damage. The high solubility of manufactured fertilizers also means that the nutrients are readily released into the soil solution. There, they may interact with the soil, or remain in solution where they become subject to uptake by plants and soil organisms, or subject to leaching rains. This rapid release of nutrients, particularly of nitrogen, requires careful timing of applications to avoid loss of nutrients to the environment.

Table 6. Typical plant-available nutrient content of commercial fertilizers.

3.36 Method and Timing of Application

Broadcast application, in which fertilizer is evenly distributed over the whole field and then usually incorporated during tillage, is best used to increase the nutrient level of the bulk of the soil. It is especially useful to build P and K when they are very deficient. Broadcasting with incorporation is usually done in the fall or in spring just before tillage. Broadcasting on top of a growing crop, called topdressing, is commonly used to apply N, especially to crops that occupy the entire soil surface, such as wheat or a grass hay crop. Lime can also be broadcast before incorporation.

Banding small amounts of fertilizer to the side and below the seed at planting is a common application method. It is especially useful for row crops grown in cool soil conditions—early in the season, for example—on soils with high amounts of surface residues, with no-till management, or on wet soils that are slow to warm in the spring. It is also useful for soils that test low to medium (or even higher) in P and K. Band placement of fertilizer near the seed at planting, usually called starter fertilizer, may be a good idea even in warmer climates when planting early.

Splitting N applications is a good management practice—especially on sandy soils, where nitrate is easily lost by leaching, or on heavy loams and clays, where it can be lost by denitrification. Some N is applied before planting or in the band as starter fertilizer, and the rest is applied as a sidedress or topdress during the growing season.

3.37 Putting it all together - Nutrient Management

To ensure that plant nutrient requirements are met efficiently and effectively and that excess polluting amounts of nutrients are not released into the environment, nutrient management should integrate

- The properties of nutrient sources which may be needed to supplement soil supplies,
- Knowledge of plant nutrient needs across the season,
- the forms and potential availability of nutrients in the soil,
- Best methods of application and placement.

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An easy way to break this down is right source, right amount, right timing, and right placement.

A. Right Source

- Does this source supply the needed elements in a form that will be available to plants in a reasonable amount of time?

How long will it take for the nutrients in this source to become available to plants?

This can be very difficult to predict for sources which must undergo mineralization or solubilization in a variable environment.

While soluble sources can be readily predicted, they can also be lost more readily through leaching, runoff, or immobilization.

- Are the nutrients in this source present in the right amounts, forms, and at ratios that will not result in excess accumulation and subsequent soil or water quality impairment?

Biosolids, compost, and manures provide a much higher ratio of P to N than is required by plants, resulting in accumulation of P when applications are based on N requirement. Over time, P status should be monitored, and application rates appropriately adjusted.

Animal and poultry operations with a DEQ permit may not apply additional manure or other organic by-products once soil test P exceeds the DCR mandated threshold for their region.

- Will the source result in damage to the plant or negatively affect yield?
- What is the cost of the source relative to the improvement in yield or quality it will produce? (See Right Amount for further discussion)
- Will this source result in unintended damage to the plant or the environment? Can those consequences be mitigated?

  Anhydrous ammonia

  Nitrate rich sources

B. Right Amount

- Must know the demands of the crops and estimate of what the soil can supply without inputs (soil testing, experience)
- Past on-farm research
- Adjusted for the season (temperature and moisture)

C. Right Timing

- Synchrony: The nutrients applied with knowledge of the source and the plant, demands within the season

- Balancing mineralization; solubility, and mobility with plant demands
- Avoid environmental damage
- Avoid deficiency, quality and yield loss

D. Right Placement

- For mobile nutrients: Near the root system at the right time
    - Split applications work best on soils prone to leaching
- For Slowly mobile nutrients (P, K and for lime to adjust soil pH): incorporate throughout the root zone, especially if know to be low (soil test)

3.38 Nutrient Management Considerations for Organic Producers

-
- Once soil chemical (nutrient levels, pH), physical, and biological conditions are optimized, organic nutrient management relies primarily on the soil food web to provide for crop nutrition. Replenish nutrients, aiming to replace approximately the amounts removed in harvest, using legume cover crops (for N), compost, and organic and natural mineral fertilizers and amendments. In addition to N, P, K, and pH, pay attention to other nutrients, especially S, Mg, Ca, B, Cu, and Zn. Because rates of nutrient mineralization (release) may not match crop needs, you may need to supplement N or other nutrients during the crop growing cycle.
- Excessive use of soluble fertilizers can reduce the diversity and activity of soil life, stimulate decomposition of soil organic matter, build up salts to levels damaging to crops and soil organisms, and contribute to soil structure degradation and erodibility. Synthetic fertilizers are not allowed in USDA certified organic production. Judicious and moderate use of soluble fertilizers (including some synthetic materials for non-organic farms) to supplement crop nutrition, in conjunction with ample organic inputs and other measures to support soil life, can be compatible with soil health. Caution: anhydrous ammonia is disruptive to soil life and is hazardous to handle.
- One nutrient management challenge for farmers who use manure and/or compost as their primary fertility inputs deserves mention. Crops consume about 8 – 10 lb N and 10 – 12 lb K for every 1 lb P. Manure, and compost that is based wholly or partly on manure,

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commonly deliver 1 lb P for every 3 lb total N, of which only 1 lb or less may be directly available to the crop. Chicken litter and organic fertilizers based thereon are particularly rich in P relative to N and K. Using manure, chicken litter, or compost to meet the crop's entire N requirement can lead to the buildup of excessive P levels. When soil test P reaches or exceeds optimum range, discontinue manure, limit compost use, and utilize N-fixing legume cover crops to provide N.

- Surplus K can also accumulate in the soil, whereas soluble N does not. Soil K levels tend to increase when hay or straw mulch and/or compost are used liberally every year. Excessive soil K can upset crop nutrition by interfering with uptake of Mg and Ca, sometimes leading to physiological disorders like blossom end rot in fruiting vegetables, and tip burn in lettuce and other greens. If soil test K is "very high," reduce use of compost and organic mulch from sources outside the field, and rely more on cover crops for N and for mulching material.
- Finally, some fungicides allowed by the National Organic Program are based on Cu and S, and their frequent use can build up these elements in the soil. If you rely on these materials for organic production of disease-prone horticultural crops, monitor soil test Cu and S levels closely.

3.39 Resources

From "Risk management for Organic Producers.

Magdoff and van Es. Building Soils for Better Crops. Nitrogen and Phosphorus management. Pg 211-225.

Magdoff & Van Es
    Chapter 7 (nutrient cycles and flows)
    Chapter 18 (nutrient management introduction)
    Chapter 19 (management of N and P)
    Chapter 20 (Other fertility issues)

3.4 Cover Crops

3.41 Why Use Cover Crops?

- Cover crops are grown primarily for soil or ecosystem improvement rather than cash, and can provide a variety of services ranging from enhanced soil quality, protection against erosion, improved nutrient cycling, and suppression of weeds

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and pests. For many organic farmers, legume cover crops are extremely important as a source of nitrogen for other crops in the rotation.

- However, cover crops can also have negative consequences if they are managed incorrectly or the wrong species are chosen.

They consume soil water that could be stored in the soil profile
The may be hosts for undesirable organisms
They require labor and field operations for planting and termination, and can complicate the planting for a following crop

- The terms cover crop, "green manure," and "catch crop" refer to different primary functions of these non-harvested crops.

Cover crop: Mainly used to prevent soil erosion by covering soil with living plants
Green manure: Crop grown mainly to be turned under for soil improvement
Catch crop: Used to "catch" or scavenge nutrients left after harvest of a cash crop and prevent leaching

- Cover crops build soil quality by supporting soil life, both while growing (through abundant root exudates) and after termination. A high-biomass grass-legume cover crop (such as winter rye + crimson clover) grown to full height and flowering, can add 3 – 5 tons/acre fresh organic residues, which break down into about 1 ton soil organic matter. Try to include one high-biomass cover crop per year in the rotation for annual cropping systems.

3.42 Choosing a Cover Crop

A cover crop must be compatible with your overall production systems, and not compromise the success of your cash crops. In making a decision to plant a cover crop, and which use, consider the following process.

- Identify the priority purpose of the cover
- Identify the niche for the cover crop - where it fits best in the system
- Select cover crop species or mix to meet these purpose and the seasonal niche

1. Identify the priority purpose of the cover

What do you think are the most important factors limiting the productivity and sustainability of your production system? Is it low fertility, poor soil structure, water quality concerns, weeds, or pest populations?

- Provide nitrogen.

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- A legume that is well adapted to your area will fix nitrogen from soil atmosphere in root nodules. The nitrogen will be available to following crops, or in the case of pastures, to interplanted grasses.
- It is important to ensure that sufficient rhizobia bacteria are present in the soil to give good root nodule formation, and hence N2 fixation.

- Prevent soil erosion.

Choose a species that rapidly covers the soil surface.

Many of the species that are good nutrient scavengers also provide excellent ground cover.

- Increase soil organic matter
  - To build soil organic matter look for a high biomass-producing cover crop that will not decompose too rapidly.
  - Possible options include non-legumes such as annual rye grass, cereal rye, or sorghum/sudan if a summer niche is identified.
- Scavenge nutrients left in the soil after the cash crop and prevent loss by leaching.
  - To maximize nutrient uptake, the cover crop should have an extensive root system that develops quickly after planting.
  - Non-legumes such as small grains, cereal rye, triticale, rapeseed, annual rye grass, oilseed radish, and mustards work well, but some legumes are also suitable.
- Suppress weeds.
  - Cover crops can reduce weed populations by outgrowing competing weeds, by established cover plants shading out newly emerging weeds, or by releasing allelopathic compounds that inhibit weed seed germination and growth.
- Provide mulch to reduce evaporative water loss and/or suppress weeds.
  - A combination of high above-ground biomass to reduce light penetration, and moderate or high C:N ratio to reduce decomposition rate is desirable. Cereal residues are most effective. Most legume residues have a high C:N, and decompose too rapidly to be effective.
- Suppress soil borne pests and diseases.

Certain cover crop species such as mustards are known to suppress particular disease or pest organisms. On the other hand, others are excellent hosts for undesirable pests and diseases (no legumes in an

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orchard ground cover). If your field is known to have a history of such pest or disease problems this will affect your choice of cover crop.

- Provide habitat for beneficial insects and spiders.

Farmscaping, the planting of strips of flowering plants has been observed to attract beneficials. More work is need to show the level of benefit to annual production systems.

- Improve soil structure.
  - Increasing soil organic matter is the key to improving soil structure, and species used for that purpose can be used.
- Improve drainage.
  - Some deep-rooted species can help to break through compacted layers in the soil and improve drainage. The roots of soil-penetrating cover crops also create channels through which water can move as the root systems decompose after death or incorporation.
- Protect water quality.
  - Species that cover the surface quickly, and have extensive root systems during the “leaching” season are preferred. It is also important to avoid turning in high N cover crops just before soils become vulnerable to leaching, e.g., when there is little or no crop nutrient uptake, high rainfall, and low evapotranspiration.

2. Identify the niche for the cover crop

- When in the season is the cover crop most needed to achieve its priority?
- What crop (and field operations) will follow?
  - In some cases, the priority and the following crop are intimately linked (I.e. providing nitrogen for a cash crop), and timely termination of the cover must carefully balance the benefits (extra nitrogen with more growth) and risks (delayed planting of a cash crop).
  - In other cases, the purpose of the cover crop may be THE priority (I.e. To provide organic matter build up for an orchard or small fruit planting the following year), and timing is not as critical.
- Will the climatic and soil conditions be suitable for planting the cover crop and for establishing the following crop? Will labor be available?
  - Examples of cool weather and warm weather cover crops
  - Winter cover crops. Most cover crops are planted in the fall to provide cover over the winter months. Examples include: annual and perennial clovers, grasses such as

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annual and perennial rye grass, or barley.

- Summer cover crops. When temperatures are high during the summer and providing water is available, fast-growing species such as sorghum/sudan grass, cowpeas, buckwheat, and others can provide a good biomass return in a short growth period.

3. Select cover crop species or mix to meet these purpose and the sesasonal niche

Once you've set the priorities for cover crop effects impact and when it must fit in the production system gather information on potential candidates.

For details on numerous cover crop characteristics see the Resources at the end of this Section.

Additional considerations:

- Consider the characteristics to avoid as well as those you want. Trade-offs are virtually inevitable, and you must decide between multiple goals.
- Consider the cost and availability of seed
- Consider the number and types of field operations required for the different options to make a sound economic assessment of the alternatives

*Adapted from: Managing Cover Crops Profitably, 3nd Edition, published by the Sustainable Agriculture Network (see Resources section).

3.43 Resources

- USDA SARE. 2007. Managing Cover Crops Profitably, 3rd Edition. USDA SARE Handbook Series Book 9. 244 pp.
- Magdoff and van Es. 2009. Building soils for better crops. Chapter 10.
- Keith R. Baldwin and Nancy G. Creamer. 2009. Cover Crops for Organic Farms. North Carolina Coop. Extension. Center for Environmental Farming Systems. Organic Production Guides.
- Kristine Moncada, and Craig Sheaffer. 2010. Chapter 13. Winter Cover Crops. Risk Management for Organic Producers. Univ. Minn.

3.5 Irrigation and Water Needs

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Plants should remain relatively free of water stress to obtain maximum yields from crops. Different crops vary in their responses to water deficits, and also at different stages of growth. Nonetheless, final vegetative and grain yields are closely associated with water availability during the season.

Access to water from ground water, a pond or other surface water, can reduce risk from drought, not only through improved yields and quality, but through improved consistency in production. Effective irrigation practices improve yields and quality, minimize water use, and protect natural resources. Internationally the concept of "amount of crop per drop" is being promoted to stress the need for improved food security with awareness of the economic and social costs of using water over 70% of the worlds fresh water to produce crops.

Things you should consider as you study this section

- Do you have access to water, especially if you are growing high value crops?
- What are the costs and benefits of adding irrigation to my farm?
- Are there permits or legal steps needed to ensure access when water is most needed?
- What irrigation methods are best suited to the cropping system?
- What is the water holding capacity of my soils? (Review section 2.1.2)
- When should water be applied? What factors need to be considered?
-

Soil Moisture, Plant Stress, and Crop Productivity

1. Reduction of yield due to water stress
    a) Water-stress-sensitive stages of crop development (prioritized)
        i. Flowering
        ii. Yield formation/fruitset
        iii. Early vegetative growth/seedling stage
        iv. Fruit ripening
2. Increased susceptibility to pests and pathogens with water stress

Crops repeatedly subjected to water stress will be less resistant and resilient to both pest and pathogens

3. Soil and Water

Saturation: all soil pores filled with water

Field Capacity: the amount soils can hold against the force of gravity

Permanent wilting point: water held by soils but unavailable to plants

Available Water holding capacity equals Permanent wilting point - Field Capacity

Crop plants reaching permanent wilting point often die, do not grow well thereafter, or are non-productive

Environmental Factors Influencing Frequency and Volume of Irrigation

1. Climate
   a) Air temperature
   b) Precipitation
   c) Humidity
   d) Wind
2. Soils
   a) Available water holding capacity (from soil survey or estimated from table below based on texture)
   b) Rooting depth of the plant
   c) Soil depth (up to 2 feet)

Soil texture	Available water holding capacity (inches of water per foot of soil)
Sand	0.25–1.00
Loamy sand	0.75–1.50
Sandy loam	1.25–1.75
Loam and silt loam	2.00–2.75
Clay loam	1.75–2.50
Clay	1.50–2.25

Table 1`. Available water holding capacity of different soil textures.

3. Stage of development and crop natural history
   a) “Water-loving” crops (e.g., celery)
   b) Drought tolerant crops (e.g., tomato varieties, winter squash varieties, Amaranth, etc.)
   c) Maturation period (e.g., onions and garlic)

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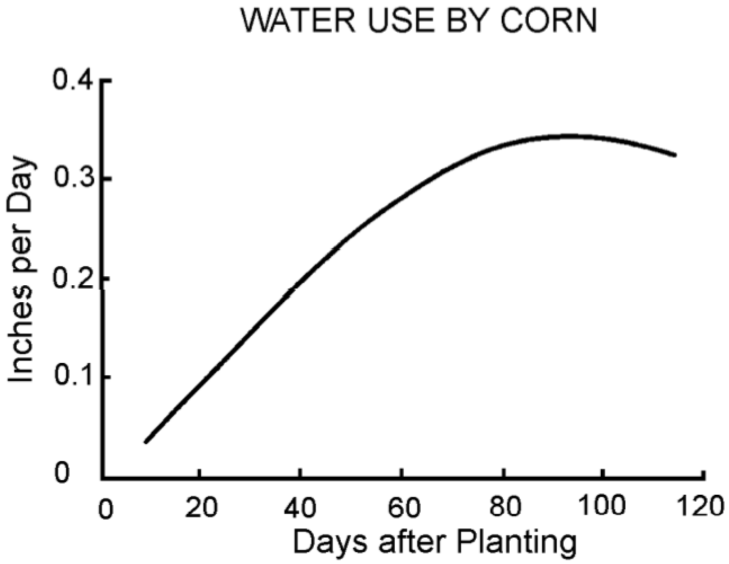

Figure 1. Water use by corn as a function of days after planting.

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Environmental Factors Influencing the Type of Irrigation Used

1. Climate and incidence of disease
    a. Drip-irrigated crops
    b. Overhead-irrigated crops

2. Irrigation Delivery Systems
1. Sprinklers
    a) Micro-sprinklers
        i. Cost
        ii. Efficiency
        iii. Application uniformity
        iv. Design considerations and requirements
    b) Hand-moved aluminum pipe with impact heads
        i. Cost
        ii. Efficiency
        iii. Application uniformity
        iv. Design considerations and requirements
2. Drip irrigation
    a) In-line emitters
    b) T-tape
    c) Header design
    d) Fertigation: Injecting soluble fertilizers through the irrigation system

Advantages of drip irrigation

1. Lower-volume water sources can be used because trickle

irrigation may require less than half of the water needed for sprinkler irrigation.
2. Lower operating pressures mean reduced energy costs for pumping.
3. High levels of water-use efficiency are achieved because plants can be supplied with more precise amounts of water.
4. Disease pressure may be less because plant foliage remains dry.
5. Labor and operating costs are generally less, and exten- sive automation is possible.
6. Water applications are made directly to the plant root zone. No applications are made between rows or other nonproductive areas, resulting in better weed control and significant water savings.
7. Field operations, such as harvesting, can continue during irrigation because the areas between rows remain dry.
8. Fertilizers can be applied efficiently through the drip system.
9. Irrigation can be done under a wide range of field conditions.
10. Compared to sprinkler irrigation, soil erosion and nutrient leaching can be reduced.

Disadvantages and limitations of drip irrigation

- Initial investment costs per acre may be higher than those of other irrigation options.
- Management requirements are somewhat higher. Delaying critical operation decisions may cause irre- versible crop damage.
- Frost protection is not possible with drip systems; if it is needed, sprinkler systems are necessary.
- Rodent, insect, and human damage to drip lines are potential sources of leaks.
- Water filtration is necessary to prevent clogging of the small emitter holes.
- Compared to sprinkler irrigation, water distribution in the soil is restricted.

Determining When to Irrigate and How Much Water to Apply

Effective irrigation of crops requires balancing the evaporative losses from the soil plus the transpiration losses from the plant (evapotranspiration or ET) against the ability of the soil to supply water to the root system. The table below shows the amount of

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expected ET required during a cropping season for several field crops.

1. Water balance approach

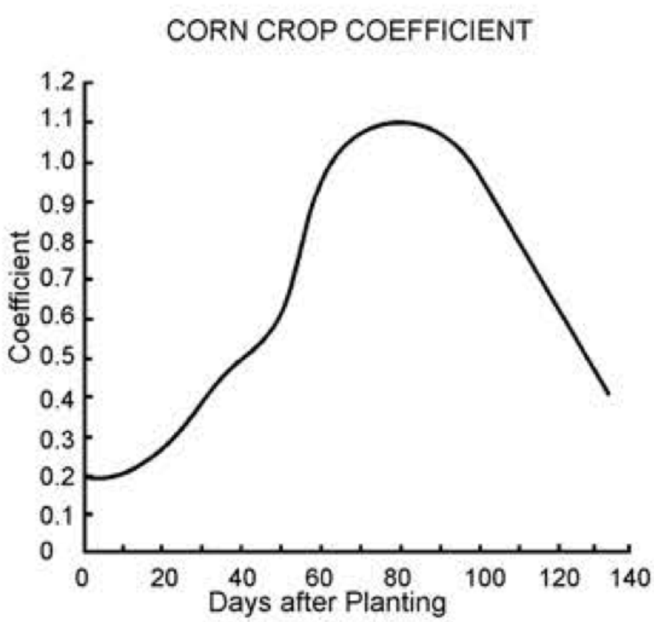
- Objective is to balance incoming water with loss of soil water through evapotranspiration. This is the sum of water lost from the soil surface by evaporation and uptake by plants (transpiration). Maintaining a balance of inputs and outputs allows soil water to be maintained within the desired range.
- Required inputs
- Soil available water holding capacity (AWHC)within the rooting depth. The maximum rooting depth to manage for most plants is 24 inches. The effective depth may be less than this for some crops, or for soils with inaccessible layers (compacted layers or low pH subsoils). The AWHC can be obtained from the soil survey for your farm (see NRCS for assistance) or estimated from the textures shown in Table 1). This number is in inches of water held per inch of soil.

The AWHC is an estimate of the water held in the rooting zone at field capacity. Typically the goal of irrigation is to keep the soil at 50% of field capacity. Not to wet, not too dry.

You will need an estimate of the daily water loss.

This can be obtained by a water use curve (See Figure 1 for a water use curve for corn.), or

Local pan evaporation data and crop coefficienct curve. The daily water use is calculated at daily pan evaporatiion x crop coefficient for the stage of growth of the crop. Figure 2 shows a crop coeffient curve for corn as a function of days after planting. Similar curves are available for several different crops (Harrison, 2012).



Teaching & Learning Tools

Figure 2. Crop coefficient for corn as a function of days after planting.

If a soil has an AWHC of 2.2 inches in the upper 24 inches of soil, then 50% of field capacity is 1.1. Inch of water. When the soil water drops below 1.1 inches (that 1.1 inches has been lost to ET), is is time to irrigate.

- You will need to know the efficiency of your irrigation method. How many inches of water do you need to apply to actually add water to the soil surface?

Drip systems are about 95% efficient, sprinklers 75 to as low as 50% efficienct.

If you are using a sprinkler system, and assume 75% efficiency, then you will need to apply 1.1 inches / 0.75 or 1.47 inches of water through your sprinklers.

If there is no rain, and your estimate of ET is for example 0.28 inches per day, you can calculate the irrigation frequency by 1.1 inches needed/0.28 inches used per day = 3.9 days supply.

Any precipitation (effectively entering the soil) can be added to the soil water supply.

Irrigation and Water Needs for Crops

The amount of water that leave the soil during the growth of a crop is called the seasonal ET. Values for several agronomic crops range from about 15" for tobacco to approximately 25 for corn. (Table 2). Early in the season water is lost primarily through evaporation from the soil surface;. As plant canopies develop, transpiration becomes dominant, and variations between crop ET requirements depend on the time of season during which the crop is grown, the water stress imposed on the crop, and the length of the growing season.

Most crops exhibit a sensitive growth period in which water deficits (Soil supply - ET) are particularly harmful to yield or quality. Table 3 gives a summary of agronomic crop growth stages that are most sensitive to water stresses, the approximate days after planting at which the critical stages occur, and the expected maximum daily water use rates during the indicated periods. These are general guides, since daily ET (or use rates) will vary with dates of planting, variety, plant population, and numerous environmental factors . The ET estimates given, however, are representative of a typical crop planted at a recommended date and population on a relatively clear day during the indicated crop growth stage. Generally, the ET requirements during the most sensitive growth stages are similar for the various crops and range

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between 0.20 and 0.28" (0.51 to 0.71 cm) per day. Table 4 shows sensitive growth stages for various fruits and vegetables. Days after planting is not shown since these are short season crops, and development rate varies considerably with cultivar and temperature during the growing season.

Table 2. Seasonal evapotranspiration requirement for several field crops.[1]

Crop	Seasonal ET (in.)
Corn	25
Grain Sorghum	20
Peanuts	22
Soybeans	23
Small Grains	20
Tobacco	15

1 From Rogers and Harrison, Water Resources Council Report No. 5 as calculated from U.S. Soil Conservation Service, Technical Release No. 21.

For grain crops, yield is determined by both the total number of seeds produced and by the weight of each seed. Thus, any stress which causes a reduction in either the number of seeds produced or the weight per seed will result in yield reductions. Growth stages that are most sensitive to water stresses are usually the growth stages during which either seed numbers or seed weights are being established (Table 1). Crop yield is generally less reduced by water stress occurring before the reproductive stages of growth.

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Some crops, including corn, sorghum, and small grains, have relatively short periods of growth during which seed numbers are determined, and severe water stress at this growth stage may be quite detrimental to grain yield. Conversely, crops such as soybeans, cotton, and peanuts determine seed numbers over relatively longer periods, and are not as severely affected by short term stresses. For a crop such as tobacco, where leaf production is most important, water stresses during most growth stages can be detrimental to yield.

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Table 3. Sensitive growth stages, dates of occurrence, and maximum daily water use required of several agronomic crops. (Wright et al., 2011)

Crop	Sensitive Growth Stage[1]	Approx. Days After Planting	Expected Maximum Water Use Requirements During Critical Growth Stage[2] (in/day)
Tobacco	2 to 3 week period near flowering[3]	50 - 65	0.22 - 0.25
Corn	Tasseling and silking	65 - 75	0.22 - 0.28
Sorghum	Early boot through bloom	45 - 70	0.20 - 0.25
Peanuts	Flowering through completion of pod set	45 - 90	0.22
Soybeans	Early to late bean fill	50 - 100	0.20 - 0.25
Cotton	Bloom period	45 - 90	0.20 - 0.25

1 Growth stage at which yield is most sensitive to water stress.

2 Value should only be used as estimates for maximum rates since many environmental factors affect water use. The range in values given for a particular crop represents values obtained from different experiments or changes associated with crop development during the critical period.

3 Represents maximum water use period. Data are limited for growth stage sensitivities.

This information is largely excerpted from the publication of Wright et al, 2011.

Teaching & Learning Tools

Peak Water Periods for Vegetables and Fruits

VEGETABLE CROPS	CRITICAL PERIOD(S)
Asparagus	spear growth, fern growth
Broccoli	transplanting, flower bud production
Cabbage	transplanting, head development
Carrot	root enlargement
Cauliflower	transplanting, curd development
Cucumber	pollination, fruit enlargement
Eggplant	transplanting, flowering, and fruit development
Lettuce	throughout growth
Lima bean	blossom and pod development
Muskmelon	pollination and fruit enlargement
Onion	transplanting and bulb enlargement
Pea	pod development
Pepper	fruit development
Potato	tuber development
Rhubarb	petiole formation for harvest
Snap bean	blossoming and pod enlargement
Spinach	throughout growth
Sweet corn	silking and tasseling, ear development
Sweet potato	when slips are set in the field
Tomato	transplanting, early flowering, fruit set and enlargement
Turnip	root enlargement
Watermelon	pollination and fruit enlargement

TREE FRUITS	CRITICAL PERIOD(S)
Apple Pears Peaches Plums Nectarines Cherries	The critical periods for these tree fruits are early fruit set, during flower formation, and during final fruit swell.

SMALL FRUITS	CRITICAL PERIOD(S)
Blueberries	berry swell to end of harvest and at fruit bud formation for next year's crop (late July and August)
Raspberries	bloom and as berries are sizing before first picking
Blackberries	bloom and as berries are sizing before first picking
Strawberries	at planting, during runner formation, during flowerbud formation before harvest begins, and at renovation

From Lamont et al, 2012

Irrigation considerations for Vegetables

- Surface water – Ponds and streams can be used for irrigation, but be very aware of what is upstream from where water is drawn. Upstream areas that are heavily grazed or have animal access to the stream pose a higher risk of contamination. ”
- Exclude animals including waterfowl and pets from ponds used for irrigation water. ” Avoid using surface water after heavy rainfall until the sediments have settled, and the water is clear again. Research has shown pathogens are higher in stormwater and in sediments.
- Use drip irrigation where practical. In general, drip is preferred to overhead irrigation because the water is less likely to coat edible portions of the crop. This is particularly true when using surface water sources.
- Consider irrigating early in the day, if overhead irrigation must be used, so sunlight and drying can reduce the level of pathogens.
- Avoid overhead irrigation of produce within two weeks of harvest. This can reduce risk but is not an absolute guarantee of safety.
- Be aware that standing water in a field can be a source for pathogens, so take care to minimize its contact with the surface of produce.

3.6 Evaporation Management

- Organic mulches such as hay, straw, chipped brush, or tree leaves provide organic matter and nutrients, suppress emerging weed seedlings, protect the soil surface from sealing and crusting, and enhance habitat for earthworms, ground beetles, and other beneficial organisms.
- Roots, stems, and other residues of cash crops left after harvest or returned to fields after crop processing (e.g., cotton gin waste), and even weeds, can make significant contribution to soil organic matter and soil quality. Mow or till weeds before they set seed or otherwise propagate. When designing a crop rotation, pay attention to the rooting habits and amounts of residue left by each production crop. Alternate deep and shallow rooted crops, and tap- and fibrous-rooted crops. Balance the potentially depleting effect of low residue crops such as salad greens or root vegetables with high residue crops such as cereal grains.

3.7 Soil Health Assessment

Teaching & Learning Tools

- In Chapter 22 of Magdoff and van Es (2009) methods of testing soil health are presented. Use of such monitoring tools over time can reassure you that your soil health is improving, or that action is needed to prevent soil degradation. Typical measures include tilth (ease of working, visible aggregation or crumb structure), degree of surface crusting or subsurface compaction, abundance of earthworms and other macroscopic soil organisms, ability of the soil to absorb rainfall without ponding or runoff, and soil moisture retention during dry spells. A penetrometer (compaction tester) can be useful for detecting a subsurface hardpan that may restrict root growth, causing crop nutrient deficiencies when soil nutrient levels are sufficient.
- Another simpler approach to soil health assessment is offered by Lamb et al. (2010) for those who are less familiar with their soils.

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3.8 Resources

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